FSW Testbed Validation Description

Flight Software Systems Branch – Code 582

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1 INTRODUCTION

1.1 PURPOSE

This Document describes the process of validating that the Flight Software (FSW) Testbed is qualified for pre-launch FSW Acceptance Test and for on-orbit FSW sustaining engineering. At GSFC, this FSW Testbed is often called the FlatSat.

1.2 SCOPE

A FSW Testbed consists of 3 major elements:

- the relevant flight data system(s) with the FSW hosted on the CPU(s),
- simulators of all external flight interfaces, and
- a Telemetry and Command (T&C) ground system.

The overall effect of the FSW Testbed is to accurately duplicate the space-flight hardware and interface environments that the FSW must accommodate post-launch. The T&C ground system provides ground-flight interfaces of the mission operations control center (without RF). The FSW Systems Branch (FSB) uses the ASIST ground system for all mission FSW test and validations.

This document is focused on the FSW Testbed validation which occurs as part of the formal FSW test program. While some Testbed verification can be accomplished by the Testbed element developers prior to delivery to the FSW Testbed, it is not possible to fully validate FSW testbed elements independent of the FSW. This is characteristic of embedded, real-time systems. The interrelationships of interfaces, timing and feedback between the FSW and its test elements demand that the FSW be executing and functional in the integrated flight-like environment, when confirming the full functionality and performance of the flight hardware, simulators and ground system.

Both verification and validation of the Guidance Navigation and Control (GN&C) Goddard Dynamic Simulator (GDS) are described in Section 3. The verification process of the deliverable hardware and 'non-GN&C' simulators at their supplier sites is not substantially discussed in this document; since the focus of this document is the integrated performance of the hardware and simulator products for purposes of FSW Acceptance.

1.3 RESPONSIBLE ORGANIZATIONS

Validation of the FSW test environment is an additional responsibility of the FSW team, since the accuracy and performance of the test environment is the basis for asserting that the tested FSW system is capable of supporting mission Integration and Test (I&T) and flight. The FSW team provides leadership and coordination of the FSW testbed process which requires active participation of relevant subsystem specialists. Other participants in the validation process of a FSW Testbed include:

- Flight Hardware developers and testers
- GDS hardware and software developers
- Science, spacecraft, power and other simulator developers as required
- ASIST ground system maintenance specialists

- T&C database developers
- FSW developers and test tool developers (e.g., flight database maintenance tools, flight data analysis/plotting tools)

Mission I&T and operations engineers may also use the FSW testbed at various times during FSW development and test, e.g., flight hardware interface tests. While their participation is not strategized as part of the FSW testbed validation process, the extra tests and insight into the FSW testbed capabilities and accuracies are significant in nature.

1.4 TERMINOLOGY

Verification confirms that a Testbed element meets its subsystem-specific requirements.

Validation confirms that the fully integrated and populated FSW Testbed accurately represents the desired on-orbit operational (nominal and anomalous) mission system.

The FSW Testbed is often called the FlatSat.

1.5 DOCUMENT ORGANIZATION

Section 2 explains the overall FSW testbed validation process as an incremental activity that starts with the flight data system and the ground system, and then adds the remaining onboard subsystem interfaces and simulators as the FSW matures and is delivered to the testbed.

Section 3 is dedicated to explaining the verification and validation processes of the highly critical GN&C GDS simulation system.

Section 4 describes the impact that mission I&T and operations preparations have on the qualification of the FSW testbed.

Section 5 provides the overall FSW testbed validation criteria.

2 FSW TESTBED VALIDATION PROCESS

2.1 OVERVIEW

FSW Testbed Verification and Validation (V&V) is an incremental process accomplished throughout the full duration of the FSW development and test program. The discipline specialists assigned to develop a Testbed element work closely with the FSW team and other relevant systems engineers, to define the FSW interfaces and functionality to be developed. Relevant requirements and ICDs are developed, reviewed and maintained. Deliveries to the testbed are defined to be consistent with the FSW capabilities of each FSW build delivery. Once developed and checked-out to the extent feasible by the development organization (using diagnostics, unit level tests, etc.), each product is integrated into the FSW testbed in a somewhat sequential fashion; as a joint effort between the FSW team and the relevant subsystem specialists.

FSW Testbed interface, functionality and performance problems discovered during FSW Build Integration tests and FSW Build Verification tests are worked to resolution as they occur.

Very rigorous configuration control of the ground system, database, simulators and FSW are practiced throughout the FSW V&V processes (see the FSW CM Plan and CM Procedures). These practices ensure that problem fixes to Testbed elements are always passed forward in tandem with new FSW build deliveries.

The testbed is not fully validated until all FSW functionality and performance data have been reviewed and analyzed by appropriate specialists in conjunction with the test input data; and their conclusion is that the completed FSW meets the demands of the mission.

2.2 VALIDATING THE GROUND SYSTEM, T&C DATABASE AND TOOLS

The ASIST ground system and database are typically integrated with the FSW while the FSW resides on a commercial or other low-fidelity flight-like processor. This enables initial verification of the FSW telemetry, commands, tables, events, logs, etc. with the ground database. Final test of the ground database occurs on the highest-fidelity Testbed, although these data definitions are typically not sensitive to Testbed hardware fidelity.

Verification of the ground database determines whether the data is packed/unpacked correctly and whether the display representations are accurate.

Since the FSW database definitions cannot be fully validated until corresponding FSW functionality has been released by the FSW development team for test, problems with the flight and/or ground T&C items may not be discovered until those FSW build deliveries have been tested.

Problems with the ground database definitions of telemetry, commands, tables, events, logs, etc. are typically fixed and retested immediately. If appropriate, DCRs are written for later implementation and retest.

While the ASIST ground system has been pre-validated for FSW test purposes by the many mission FSW test programs it has successfully supported, if new ASIST features are implemented during FSW development or test phases, those features are validated by the FSW team. Problems are worked with the ground system support team. Fixes are implemented if necessary and the feature is retested until the ground system and FSW telemetry and commands are fully consistent.

2.3 VALIDATING THE FLIGHT-EQUIVALENT DATA SYSTEM HARDWARE

FSW is developed incrementally and integrated into a series of increasingly capable builds that represent pre-defined sets of functionality of the intended FSW system. In order to reduce risks associated with flight hardware interfaces, the earliest builds are defined to include I/O and basic functional processing of data from/to the various flight hardware elements -- electronics components (e.g., computer, data buses, clocks, memory types, solid state recorders), transponders, power components, etc. Transition from a commercial, or low fidelity, hardware environment to the highest fidelity hardware environment for the FSW testbed, occurs as early as feasible during the FSW test process; in coordination with the flight hardware development team(s).

This focus on early execution of hardware/FSW interfaces has several advantages:

- maximizes the amount of time available to resolve any hardware issues
- maximizes the amount of time that the FSW will be executing with the optimum flight-like hardware
- ensures, to the greatest extent possible, that the flight hardware and FSW are both properly implemented for the start of I&T

The FSW team and the flight hardware team each implement the FSW/hardware interfaces according to Interface Control Documents (ICDs) and requirements documents that are to be baselined by the Project-level CCB. The hardware development team tests their Bread-board (BB) flight-like hardware, and Engineering Test Unit (ETU) flight-equivalent hardware, via FSW team-provided diagnostics and additional functional/performance checkout in their labs. When the FSW is hosted on the hardware of the FSW Testbed, both hardware and FSW specialists exercise the hardware/FSW system to determine if both are operating together properly.

If a hardware/FSW problem appears while executing FSW tests, the problem is isolated via collaborative work with the hardware & FSW development team(s). Isolation and characterization of the problem may require additional hardware/FSW interface tests in the FSW testbed. It’s not unusual for the hardware to be taken back to the hardware development lab for troubleshooting and refinement before being returned to the testbed. Hardware interface problems are usually worked immediately by the hardware and/or FSW team to establish the stable platform for further FSW tests.

When changes are made to the FSW Testbed hardware, the full set of FSW tests are re-run to ensure that the hardware and FSW perform properly on the upgraded hardware configuration.

Some hardware issues may be subtle or will only appear if the FSW is using the hardware in flight-like scenarios (e.g., memory access, rapid and parallel I/O), which require a level of FSW maturity not available during early integration activities. During the full range of FSW tests that exercise hardware anomaly test cases, stress tests, long duration tests, etc., the hardware continues to be carefully evaluated by the FSW team.

2.4 VALIDATING ADDITIONAL FLIGHT HARDWARE INTERFACES AND SIMULATORS

The test of non-data-system hardware interfaces in the FSW testbed is typically accomplished via high fidelity hardware interfaces and dedicated software simulators that respond to FSW data sent over the interfaces and drive the contents of the data transfers back to the FSW. These interfaces may include GN&C sensors and actuators, antennae, solar arrays, batteries, science instruments, spacecraft (in the case of an instrument FSW development), or another special purpose flight subsystem.

These interfaces are defined by requirements and ICDs that will be approved and baselined by the Project-level CCB. Unfortunately the development of FSW testbed products often precedes the Project-level approval process, so the test/validation process can be incremental and repetitive.

Simulators for FSW test will have varying fidelities depending on the functionality and performance of the FSW to be tested. The GN&C GDS simulator validation process is described in detail within Section 3 due to the criticality of this particular simulation capability to the overall mission success. The following applies generically to any simulator developed for the FSW Testbed to support FSW test.

Once again, FSW build definitions tend to be defined to include early onboard hardware I/O and processing from/to simulators. The focus on detecting and resolving flight hardware interface issues early, is considered a significant risk reduction priority.

Flight interface hardware and simulator software are tested by the simulator developer at the interface and unit level before delivering to the FSW test environment. The integration of the simulator into the FSW test environment is supported by the FSW team and the simulator team. Integration tests are exercised to check-out the basic functionality and performance of the interfaces, the simulations and the FSW. Detected problems are fixed immediately.

Following simulator integration test, the FSW team uses the simulator during FSW build- and system-level tests. Complex simulations such as closed-loop power management and science will require a variety of FSW tests to fully validate the functionality and performance of the simulation system. This level of check-out will persist through-out the entire FSW test validation process. As problems surface, an evaluation determines if the problem is in the FSW or in the simulator. This evaluation may require the relevant subsystem experts to review the FSW inputs and outputs in conjunction with the simulator inputs and outputs. Occasionally special FSW tests (and simulator configurations) may be required in order to isolate the source of a problem. Once the source is identified, the problems are formally documented via DCRs against the FSW and/or the simulator. Once the DCR resolution is implemented, the FSW test(s) are re-run and the discipline experts again review the inputs and outputs until the results are confirmed to reflect exactly how the flight hardware and external subsystems will perform.

See Section 3 for a detailed explanation of GN&C validation of the FSW testbed.

3 VALIDATING THE GN&C DYNAMIC SIMULATOR

The GN&C FSW simulator deserves special explanation, in addition to the generic description above, due to its complexity and criticality to mission success. The GSFC Dynamic Simulator (GDS) is a collaborative product between Codes 596 and 582. The former provides overall leadership, the GN&C hardware equipment and the algorithms that model the space-flight environment and the GN&C hardware behavior in response to FSW commands. The latter provides the software implementation of the interfaces and simulation models that will interact directly with the FSW in the FSW testbed.

The GDS development follows very strict hardware and software tests by the development organizations. GDS hardware testing is performed by the GDS hardware team prior to, and in conjunction with, delivery of the hardware to the GDS software team. Hardware tests include 'Safe to Mate' and 'Functional Tests' using additional power supplies, break out boxes, meters and scopes as appropriate.

The software team implements only defined and agreed upon GDS requirements. Code walk-throughs are routine. GDS unit tests are thorough and are written in advance of developing the software --which ensures clear understanding of the required capabilities and expected software behavior. Unit tests use a well established GDS unit test framework. Once released, each change to a GDS unit results in a re-run of the GDS unit tests.

Automation of GDS software tests is inherent in the GDS design for repeated exhaustive test and retest of GDS code. As new code is implemented, appropriate tests are added into the automated GDS test structure. Automated (requires no user participation) tests are written to verify implementation of each GDS command statement and other infrastructure code, all GN&C models and their supporting packages, plus all 1553 bus transactions. In addition, all hardware modules and their supporting packages are run on the GDS software development rack, which contains one of each kind of PCI or IP card interconnected by test harnesses. A software simulation of some of the GDS PCI and IP cards allows hardware interface tests without the actual hardware. This latter capability also allows system level test executions without actual hardware. So GDS hardware module tests can be run with either real or simulated hardware in the loop, driven by real or simulated test hardware. Expected results of GDS automated tests are defined within the tests themselves and are verified with documentation during GDS test execution.

GDS software integration tests are defined to test software modules with input/output dependencies, e.g., a GN&C hardware component and a GN&C model; and to test modules with on-orbit effects relationships, e.g., an actuator model has the correct impact on spacecraft motion. Integration tests are fully automated and executed via named test scripts in the model/test directory. These tests include sufficient 'verify' statements in-line to demonstrate that the modules under test are each functioning correctly.

Prior to delivery of a GDS build to the FSW testbed, the GDS is executed in conjunction with the ASIST T&C workstation, where GDS commanding and GDS telemetry are verified.

FSW Build Integration Test is the first time the GDS and the FSW are integrated in the context of their target hardware data system. The GDS team provides an initial GDS start-up script as an ASIST test procedure, which becomes integrated with a FSW start-up procedure. At this point specific and generic GDS hardware and software tests are executed with the feedback of the FSW executing in a closed-loop fashion. The FSW development team is similarly reviewing FSW data to verify that the expected FSW results are happening. Once the GDS, FSW and T&C database are stable, the FSW team initiates their own set of planned integration tests. Problems between the GDS and FSW are resolved either immediately or with the consulting support of the GN&C analysts as necessary to isolate functional problems between the GDS software and the FSW. DCRs are written against the GDS or the FSW as necessary.

During FSW Build Verification Test, FSW and GDS data may be provided to the GN&C analyst team for analysis of both expected and unexpected GN&C test results. Some FSW build test results will be compared with similar runs on the analysts' HiFi simulator. Comparison of the inputs and output from the matching runs provides high confidence that the GDS, FSW and other elements of the FSW test environment are indeed functioning as desired for on-orbit performance.

FSW System Validation Test is a FSW test phase in which on-orbit operations-like scenarios are implemented and executed on the FSW Testbed to determine if the FSW behavior meets the intended operational needs. A large proportion of the FSW system tests are anomalous in nature, to ensure that the FSW can respond to and recover from non-nominal onboard events. These data are again provided to the GN&C analyst team for confirmation of the FSW and GDS behavior. DCRs are again written and resolved as appropriate with FSW/GDS retests until the full set of FSW and GDS functionality has been implemented and validated.

4 INTEGRATION AND TEST (I&T) PLUS OPERATIONS READINESS

When the FSW is hosted on the actual mission flight electronics and executed during I&T, FSW performance with the flight hardware is again exercised and questioned. If the FSW and flight hardware perform entirely as expected during I&T interface tests, functional tests, comprehensive performance tests, environmental tests and pre-launch mission simulations, then the FSW test results on the actual flight hardware are an additional confirmation that the FSW Testbed hardware and simulations are identical to the mission flight hardware characteristics.

If a problem arises during tests with the actual flight hardware, and that same behavior can be reproduced on the FSW Testbed, it's clear that the testbed hardware performs similarly to the flight hardware. If the decision is made to modify the flight hardware, it is hoped that that same 'fix' will be implemented on the FSW testbed hardware. If that is accomplished and retests are performed, then the FSW testbed is again confirmed to be identical to the flight hardware. This is certainly the preferred option for long term FSW maintenance purposes.

If a problem arises during I&T of the actual flight hardware, and that same behavior is not reproducible on the highest-fidelity FSW testbed environment, then there is a difference between the two test environments. Exhaustive tests are typically performed to characterize the differences and determine the criticality of the problem to the space-flight mission. If the problem needs to be fixed on the flight hardware, hopefully that same fix will be incorporated into the FSW testbed environment.

If the decision is to leave the flight hardware alone and, if necessary, provide a work-around (perhaps a FSW change) and not change the FSW testbed (presumably following exhaustive risk analysis) then any difference between flight hardware and the FSW testbed needs to be carefully documented and passed on to the FSW maintenance team.

If a hardware characteristic during I&T differs from the FSW Testbed hardware, and analysis determines that the testbed is incorrect but the flight unit is correct, then it is hoped that the FSW testbed will be upgraded to meet the accurate characteristics of the flight hardware – again following careful on-orbit FSW sustaining engineering risk analysis.

Regardless of the decisions, the I&T and launch readiness test activities provide additional confirmation of FSW testbed qualification for launch and on-orbit maintenance. As long as risk analysis is performed and documented, and any work-arounds are clearly documented and validated, the FSW testbed is again ready to support launch and long term on-orbit sustaining engineering.

5 FINAL FSW TESTBED VALIDATION CRITERIA

This process of finding, isolating, resolving, retesting and confirming test results continues through the full FSW development test processes. Problems that are immediately obvious are fixed. DCRs are written. DCRs are implemented and retests are executed. Each flight hardware interface, each data handling and data presentation requirement, each closed-loop demand and each tool have all been proven to satisfy the on-orbit operational mission requirements; and no critical DCRs remain open.

When the flight data system hardware and the relevant power, communications, GN&C, and science hardware in the FSW Testbed – whether real or simulated -- plus the modeled dynamics relevant to the on-orbit environment/onboard behavior have all been confirmed to be correct by the relevant discipline experts, and the FSW has been evaluated to have successfully met FSW Acceptance Test on the Testbed; and the FSW has executed similarly successfully on the actual flight hardware during I&T and launch readiness preparations, then the FSW Testbed has been validated.